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FIRE-SAFE FUEL: FUEL PROPERTIES AND
SYSTEM COMPATIBILITY STUDIES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) In conjunction with the coordinated Fire-Safe Fuel (FSF) Program, a study was conducted to assess the effects of the FSF additive (5% vol. Bromochloromethane) on diesel fuel performance criteria, elastomer compatibility, and potential system corrosion tendencies. Laboratory techniques were employed to define those changes in basic fuel properties/characteristics resulting by additions of the Bromochloromethane. In addition, accelerated tests revealed potential elastomer-fuel incompatibility and corrosion problems occurring from the possible use of FSF.		

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TABLE OF CONTENTS

	<u>Page No.</u>
DD FORM 1473	i - ii
INTRODUCTION	1
DETAILS OF TEST	1 - 5
RESULTS OF TEST	6 - 8
CONCLUSION AND RECOMMENDATIONS	8
LITERATURE CITED	8 - 9
APPENDIX A	10
Tables 1 - 12	11 - 22
DISTRIBUTION LIST	23 - 29

I. INTRODUCTION

The fuel fire hazard problem associated with armored vehicles operating in hostile environments resulted in the initiation of a research program (1) designed to explore the possibilities for developing a "fire-safe diesel fuel". This approach considered the introducing of an additive to the fuel permitting, in effect, an "in situ" fire extinguisher functioning as an existing component of the fuel blended under conditions of ballistic penetrations. The additive initially considered was a halogenated hydrocarbon, Dibromomethane, which was found to be effective (at a seven to ten percent concentration level) in reducing fuel fires associated with ballistics penetrations. With the introducing of this additive into the fuel, engine performance and operational problems were anticipated due to the chemical characteristics of this fire-safe fuel additive. Since this office maintains the custodial responsibility for the fuels used by Army equipment, the effect of this additive on diesel fuel specification requirements as they relate to performance criteria was of immediate concern. A limited study (2) was subsequently conducted to ascertain those areas where addition of Dibromomethane altered the specification requirements of Federal Specification VV-F-800a and where potential corrosion/system incompatibility problem could occur.

More recently, a cooperative Fire-Safe Fuel Research Program was formulated to address all aspects of this problem. Program input was collated from Terminal Ballistics Laboratory, U.S. Army Fuels & Lubricants Research Laboratory, and Coating and Chemical Laboratory into a coordinated test plan and forwarded to US Army Tank Automotive Command who was assigned the lead laboratory function. At this point in time, the candidate fire-safe fuel (FSF) additive was changed from Dibromomethane to Bromochloromethane (BCM) since this latter compound could be used at a lower concentrations (5% vol. as compared to 7 - 10% vol.) while maintaining its effectiveness as an "in situ" fire extinguisher. As part of the coordinated FSF Research Program, this Laboratory agreed to assess (1) effects of 5% BCM on diesel fuel performance characteristics as they relate to engine operation and projected fuel specification requirements, (2) the compatibility of BCM-diesel fuel blends on elastomer components present in fuel delivery systems, and (3) the potential corrosion problem occurring as a result of BCM additions. To provide this basic data, laboratory bench-scale and accelerated-type test procedures were conducted using representative diesel fuels. This report describes the results of these findings.

II. DETAILS OF TEST

A. Selecting Test Fuel and Additive Combinations

To assess the changes in fuel property and specification requirements (i.e., gravity, viscosity, volatility, etc.) resulting from BCM additions, three representative diesel fuels meeting Federal Specification VV-F-800a Fuel Oil, Diesel were obtained for this study. The three fuels selected

were as follows:

- * Fuel A - A grade DF-1 diesel fuel typical of fuel procured for Post-Camp-and-Station operation of Army activities.
- * Fuel B - A Reference DF-2 diesel fuel specified for use in engine oil (MIL-L-2104C) qualification testing programs.
- * Fuel C - A candidate Referee DF-2 diesel fuel meeting MIL-F-46162 Fuel Oil, Diesel, Referee Grade.

The intent in having three base fuels for evaluating fuel property and compatibility effects was to provide a wide range of fuel quality (within specification limitations) to encompass the many types/characteristics of diesel fuels available (i.e., diesel fuel produced by atmospheric pipe-still distillation, diesel fuel produced by blends of pipe-still distillate and catalytic cracked fractions, diesel fuel produced by blends of coker gas oil, catalytic cracked fractions, and kerosene, etc.). In addition to providing this wide base of fuel quality, the effects of other additives potentially present was also considered. More specifically, many commercial diesel fuels and those procured under VV-F-800a contain small amounts (up to 0.5% vol.) of cetane improver additives which are designed to improve the cetane quality of fuel. The type of organic compound approved for use in VV-F-800a is Alkyl Nitrate Esters. Since the three base fuels did not contain any cetane improver, an approved cetane improver (Amyl Nitrate) was included in this study. Similarly, since Fuel System Icing Inhibitor (MIL-I-27682) which is essentially Ethylene Glycol Monomethyl Ether (EGME) is being used in diesel fuel as a fuel de-icer and biocide additive, it was also included. The evaluation of these two additives in combination with the 5% BCM would provide an assessment of their synergistic or anti-synergistic effects relative to fuel property changes, elastomer compatibility and corrosion tendencies.

B. Fuel Property Evaluations

The determining of possible changes to fuel property characteristics resulting from the introduction of BCM was to be accomplished by analyzing the neat fuels and those containing 5% vol. of BCM. Similarly, the synergistic/anti-synergistic effects of the "other additives" (0.5% vol. Amyl Nitrate + 0.5% vol. EGME) would be assessed by analyzing the fuels containing all three additives; namely, 5% BCM, 0.5% Amyl Nitrate, and 0.5% EGME. To accomplish this, two sets of blends were prepared for each base fuel as follows: (1) a blend of diesel fuel and 5.0% vol. of BCM, and (2) a blend of diesel fuel, 5.0% BCM, 0.5% vol. Amyl Nitrate, and 0.5% vol. EGME. For the remainder of this report, "Others" or "Other Additives" in the ensuing tables shall refer to the latter blend. Prior to the analysis of the "neat", "+ 5% BCM", and "+ Others" fuel blends, a sample of the "technical grade" of BCM was given a cursory analysis. The results of this limited analysis on BCM is shown on Table 1 (Appendix A). To assess the changes in fuel properties between

the neat and fuel blends, all current VV-F-800a specification inspection requirements were performed. In addition to these standard test procedures, other methods were included to further define possible changes in fuel characteristics that could alter fuel system performance and/or engine operation, namely, the following:

- * Dielectric Constant
- * Surface Tension
- * Interfacial Tension
- * Emulsion Tendencies
- * Existent Gum

It should be noted that the Cetane Number (ASTM D 613) was not determined due to the possibility of engine corrosion and unknown exhaust gas toxicity. To provide some relative measure of cetane quality effect, the Cetane Index (ASTM D 976) was calculated for the " + 5% BCM" blends. It is recognized however, that these extrapolations may not be completely valid due to the nature of the resultant blend. Accordingly, the results of these analysis on Fuel A and blends, Fuel B and blends, and Fuel C and blends are presented on Tables 2, 3, and 4 (Appendix A).

C. Fuel-Elastomer Compatibility Assessment

To assess the effects of BCM in diesel fuel, accelerated test procedures were employed. In general, fuel resistance of elastomeric vulcanizates is determined by direct immersion of samples in specific test fluids (as outlined in ASTM D 471 - Changes in Properties of Elastomeric Vulcanizates Resulting From Immersion in Liquids) for varying time-temperature periods. After these immersion periods, measurements such as % volume increase (swell), loss in tensile strength, and hardness change are employed as an indicator of elastomer resistance to certain fuel/fluid environments (i.e., the lower or smaller the changes, the greater the resistance or satisfactory compatibility). Owing to these wide variations of time-temperature conditions, no direct correlation between static immersion testing and service performance may be implied. However, an indication of potential problems is provided when significant changes in these properties occur after the static immersion test. In a previously conducted study (3), the effects of diesel fuel-alcohol blends on fuel system elastomer components were investigated using a static immersion test interval of 16 hours at 70°C. Since these test conditions were developed to encompass fuel system temperature anticipated in those geographic areas where fuel-deicers were required, a more severe test (temperature-wise) was needed for evaluating the FSF blends. To this end, it was decided that a 6 hours period at 100°C would provide the type of environment needed to assess the compatibility of representative elastomers with FSF blends. The test container selected for these compatibility studies was the Copper Strip Corrosion Test Bomb (ASTM D 130). Because of its pressure-type configuration, the loss of any volatile components during the immersion period was prevented. Using this technique,

one-inch squares of 1/16" sheet stock of representative elastomer vulcanizates were exposed to 40 ml. of fuel for the prescribed period of test. Because of the limited amount of elastomer vulcanizates available, only Percent Volume Change (ASTM D 471 - para 9) measurements on the different elastomers were determined. The types of elastomers selected for this study were as follows:

<u>ASTM D 2000 Classification</u>	<u>Abbreviation</u>	<u>Chemical Type</u>
BG	AU	Polyurethane
BC	CR	Polychloroprene (Neoprene)
FK	FSi	Fluorosilicone
HK	FPM	Fluorocarbon
--	ECO	Epichlorohydrin ethylene oxide copolymer
BF	NBR	Butadiene-acrylonitrile copolymer

Under the "NBR", three different samples were evaluated to assess the effect of high versus low acrylonitrile content. Using these eight elastomer samples, the elastomer-fuel compatibility tests were conducted with the neat fuels, the 5% BCM blends, and the "other additive" blends. Initial volume measurements were made prior to the exposure period and immediately at the termination of the test to determine the percent volume increase for the one-inch square specimens. The results of these compatibility tests are presented on Table 5 (Appendix A).

D. Corrosivity Tests

The potential corrosion tendencies of the FSF blends were determined under two exposure conditions; normal exposure (room temperature for 3 weeks) and accelerated exposure (6 hours at 100°C.). In the latter exposure situation, the same environment (test container) used in the elastomer compatibility study (Copper Corrosion Test Bomb) was employed. It was felt that this assessing of corrosivity in terms of normal and accelerated exposure conditions would provide a more meaningful indication as to the potential occurrence of engine corrosion problems. Since the engine component and fuel delivery system metallurgy varies considerably between different equipment producers (i.e., Detroit Diesel, Mack, Teledyne-Continental, etc.), it was decided that standard reference metal specimens should be initially employed to indicate those areas where further investigation was warranted. To this end, the following standard metal specimens were obtained for corrosion testing:

<u>SAE Classification</u>	<u>Type</u>
SAE 1010	Cold-Rolled Low Carbon Steel
SAE G-3000	Automotive Cast Iron
SAE AA 2024	Aluminum Alloy

The above standard specimens had the same approximate dimensions of the standard Copper Strip which facilitated their use in the Copper Corrosion Test Bomb. Although these metals were probably not exactly the types found in engine and/or fuel delivery systems, their use would provide a baseline reference as to indicating potential corrosion tendencies. The standard metal strips were polished using Silicon Carbide abrasive papers of decreasing abrasiveness followed by final polishing with #00 Steel Wool. Since there are no standard ratings of defining corrosivity for the above metal specimens, it was decided that the visual appearance would be noted as accurately as possible (i.e., staining, pitting, rusting, or as polished which would indicate no surface reaction).

In addition to the above types of test metals, recent fuel injector pump problems occurring in the AVDS 1790-2A engine (4) when operated with one particular operational/preservative engine oil (MIL-L-21260B, Type II) prompted the inclusion of one additional metal specimen; namely, 52100 Chrome-alloy steel. More specifically, during factory run-in operation with the AVDS 1790-2A engine, a surface reaction/corrosion phenomena was noted on the fuel pump plunger rod occurring at the fuel-lubricating oil interface region. Since a trace inorganic chlorine contaminant was identified in the lubricating oil and subsequent Electron Microprobe Analysis revealed high concentrations of chlorine in the "stained" fuel-lubricant interface region of the plunger rod, the corrosivity of FSF blends with this 52100 Chrome-alloy Steel was naturally very suspect (Note: the fuel pump plunger rod and fuel pump head assembly are fabricated from 52100 Chrome-alloy Steel). Because of the non-availability of 52100 metal strip specimens, test balls described in ASTM D 2596 (Measurement of E.P. Properties of Lubricating Grease: Four-Ball Method) as AISI-E 52100 Chrome-alloy Steel were used. Due to the polished nature of these test balls as obtained, no further treatment was performed prior to testing other than degreasing (solvent removal).

The corrosion tests of the four metal specimens in FSF blends under normal exposure and accelerated exposure conditions were conducted essentially neat and with 0.5% vol. distilled water added. The intent of including this trace amount of water was to simulate the separated and/or condensed water which is present in all fuel tank environments. Using this approach, the neat and FSF blends were evaluated for possible corrosion tendencies occurring at room temperature and at accelerated temperatures. Because of the numerous test conditions for the nine FSF blends (including the neat fuels), some of the corrosion tests under the normal exposure condition were omitted whereas all were conducted under the accelerated condition which represented the more severe environment. The result of the FSF corrosion tests under accelerated and normal exposure are presented on Tables 6 and 7 (Appendix A).

III. RESULTS OF TEST

A. Changes in Fuel Properties

The effect of a 5% addition of BCM alone and in combination with the other additives produced significant changes in properties for the three fuels tested. To illustrate the extent of these changes, Table 8 (Appendix A) presents the individual and average changes in fuel properties resulting from addition of the 5% BCM where Table 9 (Appendix A) presents individual and average changes resulting from addition of the other additives (5% BCM + 0.5% Amyl Nitrate + 0.5% EGME). In reviewing these changes, it would appear that the 5% BCM addition has the greatest effect on depressing Gravity, Viscosity, Distillation (Front-End) and increasing Interfacial Tension and Dielectric Constant. In combination with the other additives, there appeared to be no synergistic effects except for possibly the Interfacial Tension which decreased from an average change of + 2.2 to - 0.8. The increases in Carbon Residue and Existent Gum as shown on Table 9 occur as a result of the Amyl Nitrate (5) itself and not the other additives in combination with the 5% BCM. The significant decreases in Cetane Index (Table 8) should be viewed cautiously since the Cetane Index nomograph (which utilizes Gravity, °API and 50% evaporation distillation temperature) was developed using conventional diesel fuels blended from essentially straight-run fractions.

In summary, the changes in Gravity, Viscosity, Surface and Interfacial Tension affect diesel fuel properties as they relate to fuel pump delivery-injection systems. More specifically, the processes involving fuel atomization, spray formation, spray penetration, dispersion, and droplet size which occur during the injection interval are all affected by changes to the basic fuel properties (6). To illustrate some of the effects changes in fuel properties have on resultant injection spray characteristics, the following guide/outline was given (6):

Changing Fuel Property	<u>Resultant Effect on Injection Spray Characteristics of:</u>			
	<u>Break-Up Distance</u>	<u>Penetration</u>	<u>Dispersion</u>	<u>Droplet Size</u>
Increasing Viscosity	Increase	Increase	Decrease	Increase
Reducing Surface Tension	Decrease	Decrease	Increase	Decrease
Increasing Density	Increase	Increase	Decrease	Increase

B. Elastomer Compatibility

The elastomers selected for this compatibility assessment are all designed to have satisfactory resistance to fuels and petroleum oils. Within the limitations of this test (6 hours @ 100°C. and the surface area to fuel

ratio), all elastomers generally gave % vol. swell measurements in the neat fuels (i.e., up to 15%) except for the Neoprene which gave consistently high % vol. swell for all three neat fuels. This may be a result of the differences in recipes used in formulating the Neoprene or the difference in slab vulcanizate versus molded components which are used in fuel delivery systems. To more clearly define the effects of additions of 5% BCM on elastomers tested, Table 10 (Appendix A) tabulates the change/increase in % vol. swell (i.e., % vol. swell of 5% BCM blended - % vol. swell of neat fuel) for all three fuels and the average change/increase. Similarly, Table 11 (Appendix A) presents the tabulated change/increase in % vol. swell for the "other additive" blends.

In reviewing these data, it is very evident that the 5% BCM had the least effect (relative to volume change) with the two fluorinated elastomers whereas the greatest effects were evidenced with Polyurethane, Neoprene, and Nitrile-LA formulations. Average changes of % vol. swell in the + 10 to + 15 range should be regarded as significant in view of material design parameters for elastomers. The additions of the other additives with respect to % vol. swell measurements did not effect significant changes over those obtained with the 5% BCM itself. A summary tabulation of the average % volume swell changes for all three test series is given on Table 12 (Appendix A). Although % volume change was the only measurement used to assess the compatibility of FSF blends, other design parameters for elastomers such as hardness, elongation, tensile strength loss, etc. would have been affected in a similar fashion due to the inter-relationship of these physical properties. For example, increase in volume change will generally be accompanied by decreased hardness, increased elongation, and decreased tensile strength.

C. Corrosion Tendencies

The assessing of corrosion tendencies at two exposure conditions provided a means of predicting whether FSF blends would react with automotive diesel fuel delivery/injection systems. The accelerated exposure conditions (6 hours @ 100°C.) produced some surface reactions on Cast Iron and Steel with two of the fuel blends and no water present whereas severe surface reactions were produced with all fuels and all metals tested. This is particularly significant as it is impossible to maintain completely dry fuel systems. Equally noteworthy was the surface reactions occurring on the 52100 Chrome-Steel balls after exposure to the FSF blends containing the water contaminant. It should be noted however, that the test balls were evaluated on short glass tubes within the test tube containing the FSF + water to eliminate any water condensation/separation bias. The presence of this positive surface reaction would indicate that possible corrosion problems could occur in the fuel pumps previously reported (4).

The normal or laboratory environment exposure conditions (3 weeks at 22°C.) produced considerably less surface reactions on the metal specimens than those described in the preceding paragraph. It is interesting to note that without the water contaminant, surface reactions occurred on aluminum

for all three FSF blends whereas no corrosion/pitting occurred with the same blends when exposed to the accelerated environment (6 hours @ 100°C). One possible explanation of this anomaly may be due to the different times of exposure and moisture adsorption from the ullage area. The results of those tests conducted in the presence of water all correlated in terms of surface reactions with preceding corrosion tests conducted at the higher temperature conditions.

IV. CONCLUSION AND RECOMMENDATIONS

The potential introduction of FSF into armored combat vehicles has resulted in completion of program to (1) assess possible changes in fuel property/characteristics and (2) investigate compatibility of FSF with materials present in diesel fuel delivery and engine systems. Representative fuels were evaluated with the FSF additive and those fuel properties exhibiting the greatest change were Gravity, Viscosity, Distillation, and Interfacial Tension. Of these, Gravity has the most significance relative to fuel system performance/operation.

Limited studies were conducted to assess the compatibility of FSF blends with representative elastomers and the potential corrosivity effects of FSF blends with standard reference metals. These data revealed that certain elastomers currently in use may degrade with FSF due to excessive swell and loss in physical properties. Additionally, the preliminary corrosion studies indicate that in the presence of trace water, FSF will react with all metals tested. In some instances, reactions of certain metals and FSF occurred without introducing the 0.5% water contaminant.

In view of the above data, it is recommended that additional elastomer compatibility and system corrosion studies be conducted to further define the extent and magnitude of this potential problem. Factors to be considered in this proposed study would encompass evaluating molded elastomer components in FSF under varying temperature-time conditions, and investigating FSF corrosion tendencies on actual fuel system metallurgy in terms of laboratory tests in simulated service systems.

V. LITERATURE CITED

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APPENDIX A

TABLE 1

INSPECTION TEST DATA ON TECHNICAL GRADE BCM^{1/}

Inspection Test	BCM
Specific Gravity @ 75°F.	1.842
Distillation, °F.:	
IBP	126
5% Evap.	138
10% Evap.	141
20% Evap.	147
30% Evap.	148
50% Evap.	151
90% Evap.	167
E.P.	205
Dielectric Constant	33.05
Kinematic Viscosity, cSt. @100°F.	Less than 0.5

^{1/}Technical Grade Bromochloromethane reported to be the following:

85% Bromochloromethane
5% Dibromomethane
10% Methylene Chloride

TABLE 2 - INSPECTION TEST DATA ON FUEL A & FSF BLENDS

Inspection Test	Fuel A, Neat	+ 5% BCM	+ Others ^{1/}	ASTM Method
Gravity, °API	41.1	31.2	32.4	D 287
Kin. Viscosity @100°F., cSt.	1.65 (1.4 - 3.0) ^{2/}	1.43	1.40	D 445
Flash Point, °F.	130 (104 min.)	+230	+230	D 93
Distillation, °F.:				D 86
IBP	330	152	--	
5% Evap.	370	238	--	
10% Evap.	382	350	--	
20% Evap.	345	388	--	
50% Evap.	426	426	--	
90% Evap.	438 (572 max.)	435	--	
EP	533 (626 max.)	534	--	
Cloud Point, °F.	-50	-60	-44	D 2500
Pour Point, °F.	-70 (-40 max.)	-75	-70	D 97
Carbon Residue, 10% BTMS, % Wt.	0.09 (0.15 max.)	0.09	0.24	D 524
Cetane Index	45.4 (45 min.)	28.0	--	D 976
Sulfur, % Wt.	0.58 (0.50 max.)	--	--	D 1551
Total Acid No.	Nil	Nil	Nil	D 664
Dielectric Constant	22.34	22.74	22.89	--
Surface Tension, dyne/cm ²	26.7	26.7	26.8	D 971
Interfacial Tension, dyne/cm ²	32.1	34.2	33.5	D 971
Copper Corrosion	1B (1 max.)	1A	1A	D 130
Emulsion Tendencies:				FTM 550
After 1st Cycle	0	0	2	
After 10th Cycle	2	3	4	
Hydrocarbon Composition:				D 1319
Aromatics, % Vol.	78.2	--	--	
Olefins, % Vol.	10.0	--	--	
Saturates, % Vol.	51.8	--	--	
Existent Gum, mg/100 ml.	Nil	Nil	Nil	D 381

^{1/} Others include 5% BCM, 0.5% Amyl Nitrate, and 0.5% EGME.^{2/} Values in parenthesis represent current VV-F-800a specification limits.

TABLE 3

INSPECTION TEST DATA ON FUEL B & FSF BLENDS

Inspection Test	Fuel B, Neat	+ 5% BCM	+ Others
Gravity, °API	33.2	24.7	24.6
Kin. Viscosity @100°F., cSt.	3.42 (2.0-4.3) ^{1/}	2.57	2.52
Flash Point, °F.	195 (122 min.)	+230	+230
Distillation, °F.:			
IBP	416	138	--
5% Evap.	458	274	--
10% Evap.	470	445	--
20% Evap.	485	482	--
30% Evap.	498	495	--
50% Evap.	521	520	--
70% Evap.	548	546	--
90% Evap.	602 (626 max.)	601	--
EP	668 (671 max.)	675	--
Cloud Point, °F.	22	28	32
Pour Point, °F.	+5 (-10 max.)	+10	-5
Carbon Residue,			
10% BTMS, % Wt.	0.15 (0.20 max.)	0.13	0.73
Cetane Index	45.9 (45 min.)	30.3	--
Sulfur, % Wt.	0.47 (0.50 max.)	--	--
Total Acid No.	Nil	Nil	Nil
Dielectric Constant	22.60	22.95	22.95
Surface Tension,			
dyne/cm ²	29.2	28.6	28.2
Interfacial Tension,			
dyne/cm ²	22.7	24.2	23.5
Copper Corrosion	1A (1 max.)	1A	1A
Emulsion Tendencies:			
After 1st Cycle	0	0	1
After 5th Cycle	1	0	1
After 10th Cycle	2	0	2
Hydrocarbon			
Composition:			
Aromatics, % Vol.	45.0	--	--
Olefins, % Vol.	8.1	--	--
Saturates, % Vol.	46.9	--	--
Existent Gum,			
mg/100 ml.	45	42	79
Heat of Combustion			
BTU/lb	19,500	17,672	--
BTU/gal	139,483	133,145	--

^{1/}Values in parenthesis represent current VV-F-800a specification limits.

TABLE 4

INSPECTION TEST DATA ON FUEL C & FSF BLENDS

Inspection Test	Fuel C, Neat	+ 5% BCM	+ Others
Gravity, °API	34.4	25.5	25.5
Kin. Viscosity @ 100°F., cSt.	2.93 (2.0-4.3) ^{1/}	2.37	2.31
Flash Point, °F.	180 (122 min.)	+230	+230
Distillation, °F.:			
IBP	380	150	--
5% Evap.	427	238	--
10% Evap.	443	423	--
20% Evap.	468	456	--
30% Evap.	487	482	--
50% Evap.	520	516	--
70% Evap.	552	551	--
90% Evap.	602 (626 max.)	601	--
EP	652 (671 max.)	651	--
Cloud Point, °F.	20	10	24
Pour Point, °F.	-5 (-10 max.)	-10	-5
Carbon Residue,			
10% BTMS, % Wt.	0.17 (0.20 max.)	0.13	0.56
Cetane Index	49.2 (45 min.)	30.5	--
Sulfur, % Wt.	0.21 (0.50 max.)	--	--
Total Acid No.	Nil	Nil	Nil
Dielectric Constant	22.53	22.94	22.97
Surface Tension, dyne/cm ²	28.4	28.5	28.5
Interfacial Tension, dyne/cm ²	22.5	25.6	22.7
Copper Corrosion	1A (1 max.)	1A	1A
Emulsion Tendencies:			
After 1st Cycle	1	0	3
After 5th Cycle	2	1	3
After 10th Cycle	2	1	5
Hydrocarbon			
Composition:			
Aromatics, % Vol.	38.3	--	--
Olefins, % Vol.	10.4	--	--
Saturates, % Vol.	51.3	--	--
Existent Gum, mg/100ml.	29.6	32.0	52.0

^{1/}Values in parenthesis represent current VV-F-800a specification limits.

TABLE 5

ELASTOMER-FUEL COMPATIBILITY^{1/} TEST DATA

Volume Change (% swell) using:	Fuel A			Fuel B			Fuel C		
	Neat	+5% BCM	+ Others	Neat	+5% BCM	+ Others	Neat	+5% BCM	+ Others
Polyurethane	8.8	17.0	16.6	12.2	19.1	21.5	11.8	21.9	21.6
Neoprene	51.8	63.1	64.0	64.0	74.2	78.8	55.1	69.9	71.7
Fluorosilicone	8.3	10.4	12.5	6.2	8.6	11.8	6.4	10.3	8.5
Fluorocarbon	6.2	7.0	7.5	5.2	6.0	8.0	5.9	7.6	7.0
Polyester	9.8	15.3	16.3	13.2	19.1	21.6	13.1	19.2	21.8
Nitrile-HA ^{2/}	7.1	8.1	9.7	5.2	6.6	7.6	6.3	16.7	8.6
Nitrile-MA ^{3/}	3.8	9.3	10.4	13.0	19.5	15.3	7.7	14.6	14.5
Nitrile-LA ^{4/}	11.4	18.3	19.6	14.8	24.4	26.1	15.7	24.8	26.1

^{1/} Compatibility test involved using D 130 Copper Corrosion Bomb Apparatus and employing test conditions of 6 hours @ 100°C. (212°F.).

^{2/} High Acrylonitrile Content

^{3/} Medium Acrylonitrile Content

^{4/} Low Acrylonitrile Content

TABLE 6 - CORROSION TESTS WITH FSF BLENDS - ACCELERATED EXPOSURE^{1/}

	Fuel A			Fuel B			Fuel C		
	Neat	+5% BCM	+ Others	Neat	+5% BCM	Others	Neat	+5% BCM	+ Others
<u>Metal Strip Ratings After 6 Hrs. @100°C.:</u>									
Cold-Rolled Steel	AP ^{2/}	AP	AP	AP	AP	AP	AP	Sl. Pitting	AP
Automotive Cast Iron	AP	Sl. Pitting	Sl. Pitting	AP	AP	AP	AP	AP	AP
Aluminum Alloy	AP	AP	AP	AP	AP	AP	AP	AP	AP
<u>Metal Strip Ratings After 6 Hrs. @100°C. With 0.5% Water:</u>									
Cold-Rolled Steel	V Sl. Rust	Sl. Stain	Sl. Stain	Sl. Stain	Sl. Pitting	Hvy. Pitting	Sl. Stain	AP	Med. Stain
Automotive Cast Iron	AP	Hvy. Pitting	Med. Pitting	Sl. Stain	Hvy. Stain	Sl. Stain	Sl. Stain	Sl. Pitting	Med. Stain
Aluminum Alloy	AP	Hvy. Pitting	Hvy. Corrosion	AP	Hvy. Corrosion	Hvy. Corrosion	AP	Hvy. Corrosion	Hvy. Corrosion
52100 Chrome-Steel ^{3/}	AP	Sl. Stain	Mod. Pitting	AP	Sl. Stain	Sl. Pitting	AP	Sl. Pitting	Mod. Pitting

^{1/} 6 Hours @100°C. (212°F.)^{2/} As polished condition with no visible indication of staining, discoloration, pitting, etc.^{3/} Metal strip specimens were available so test balls of AISI-E-52100 Chrome-alloy Steel specified under ASTM D 2596 were employed.

TABLE 7 - CORROSION TESTS WITH PSF BLENDS - NORMAL EXPOSURE^{1/}

	Fuel A			Fuel B			Fuel C		
	Neat	+5% BCM	+ Others	Neat	+5% BCM	+ Others	Neat	+5% BCM	+ Others
Metal Strip Ratings After 3 Weeks @R.T.:									
Cold-Rolled Steel	AP ^{2/}	AP	--	AP	Sl. Stain	--	AP	AP	--
Automotive Cast Iron	AP	AP	--	AP	Sl. Stain	--	AP	AP	--
Aluminum Alloy	AP	Sl. Pitting	Sl. Stain	AP	Sl. Stain	Sl. Stain	AP	Sl. Stain	Sl. Stain
Metal Strip Ratings After 3 Weeks @R.T. With 0.5% Water:									
Cold-Rolled Steel	--	Sl. Rust	--	--	Sl. Stain	--	--	Sl. Stain	--
Automotive Cast Iron	--	Mod. Rust	--	--	Sl. Stain	--	--	Mod. Rust	--
Aluminum Alloy	--	Sl. Stain	--	--	Sl. Stain	--	--	Sl. Stain	--
52100 Chrome-Steel ^{3/}	--	Sl. Stain	--	--	Sl. Stain	--	--	Sl. Stain	--

^{1/} Three weeks @ room temperature - 22°C. (72°F.).

^{2/} As polished condition with no visible indication of staining, discoloration, pitting, etc.

^{3/} Metal strip specimens were unavailable so test balls of AISI-E-52100 Chrome-alloy Steel specified under ASTM D 2596 were employed.

TABLE 8

CHANGES IN FUEL PROPERTIES WITH ADDITION OF 5% BCM

Inspection Test	Fuel A	Fuel B	Fuel C	Avg. Change
Gravity, °API	-8.9	-8.5	-8.9	-8.8
Kin. Viscosity @100°F., cSt.	-.22	-.85	-.56	-.54
Cetane Index	-17.4	-15.6	-18.7	-17.2
Distillation, °F.:				
IBP	-178	-278	-230	-229
5% Evap.	-132	-184	-189	-168
10% Evap.	-32	-35	-20	-29
20% Evap.	-7	-3	-12	-7
30% Evap.	-2	-3	-5	-3
50% Evap.	0	-1	-4	-2
90% Evap.	-2	-1	-1	-1
EP	+1	+7	-1	+3
Cloud Point, °F.	-10	+6	-10	-5
Pour Point, °F.	-5	+5	-5	-2
Car. Residue,				
10% BTMS	0	-.02	-0.04	-0.02
Existent Gum,				
mg/100 ml.	0	-2.6	+2.4	0
Dielectric Constant	+0.37	+0.35	+0.41	+.38
Surface Tension	0	-.6	+.1	-.2
Interfacial Tension	+2.1	+1.5	+3.1	+2.2
Total Acid No.	0	0	0	--
Copper Corrosion	0	0	0	--
Flash Point, °F.	<100	<35	<50	--

TABLE 9

CHANGES IN FUEL PROPERTIES WITH ADDITION OF OTHER ADDITIVES^{1/}

Inspection Test	Fuel A	Fuel B	Fuel C	Avg. Change
Gravity, °API	-8.7	-8.6	-8.9	-8.7
Kin. Viscosity @100°F., cSt.	-.25	-.90	-.62	-.59
Cloud Point, °F.	+6	+10	+4	+6
Pour Point, °F.	0	-10	0	-3
Car. Residue, 10% BTMS	+.15	+.58	+.39	+0.37
Existent Gum, mg/100 ml.	+1.6	+34.2	+22.4	+19.4
Dielectric Constant	+.52	+.35	+.44	+0.44
Surface Tension	+.1	-1.0	+.1	-0.3
Interfacial Tension	+1.4	+.8	+.2	+0.8
Total Acid No.	0	0	0	--
Copper Corrosion	0	0	0	--
Flash Point, °F.	<100	<35	<50	--

^{1/} Other Additives include 5% vol. BCM, 0.5% vol. Amyl Nitrate, and 0.5% vol. Ethylene Glycol Monomethyl Ether.

TABLE 10

CHANGES IN ELASTOMER SWELLING^{1/} DUE TO 5% BCM

Elastomer Tested	Fuel A	Fuel B	Fuel C	Avg. Change
Polyurethane	+8.2	+6.9	+10.1	+8.4
Neoprene	+11.3	+10.2	+14.8	+12.1
Fluorosilicone	+2.1	+2.4	+3.9	+2.8
Fluorocarbon	+.8	+.8	+1.7	+1.1
Polyester	+5.5	+5.9	+6.1	+5.8
Nitrile-HA	+1.0	+1.4	+10.4	+4.3
Nitrile-MA	+5.5	+6.5	+6.3	+6.1
Nitrile-LA	+6.9	+9.6	+9.1	+8.5

^{1/} Values shown represent arithmetical difference in volume swell between 5% BCM blend and neat fuel after compatibility test (6 hours @210°F.).

TABLE 11

CHANGES IN ELASTOMER SWELLING^{1/} DUE TO OTHER ADDITIVES^{2/}

<u>Elastomer Tested</u>	<u>Fuel A</u>	<u>Fuel B</u>	<u>Fuel C</u>	<u>Avg. Change</u>
Polyurethane	+7.8	+9.3	+9.8	+9.0
Neoprene	+12.2	+14.8	+16.6	+14.5
Fluorosilicone	+4.2	+5.6	+2.1	+4.0
Fluorocarbon	+1.3	+2.8	+1.1	+1.7
Polyester	+6.5	+8.4	+8.7	+7.9
Nitrile-HA	+2.6	+2.4	+2.3	+2.4
Nitrile-MA	+6.6	+2.3	+6.8	+5.2
Nitrile-LA	+8.2	+11.3	+10.4	+10.0

^{1/} Values shown represent arithmetical difference in volume swell between additive blends and neat fuel after compatibility test (6 hours @210°F.).

^{2/} Other Additives include 5% BCM, 0.5% Amyl Nitrate, and 0.5% Ethylene glycol monomethyl ether.

TABLE 12

ELASTOMER - FUEL BLEND COMPATIBILITY SUMMARY

Elastomer Tested	Neat Fuels Avg. Vol. Change	5% BCM Fuel Blends - Avg. Vol. Change	Other Additive Fuel Blends - Avg. Vol. Change
Polyurethane	10.9	16.0	19.9
Neoprene	57.0	69.1	71.5
Fluorosilicone	7.0	9.8	10.9
Fluorocarbon	5.8	6.9	7.5
Polyester	12.0	17.8	19.9
Nitrile-HA	6.2	10.4	8.6
Nitrile-MA	8.2	14.4	13.4
Nitrile-LA	14.0	22.5	23.6